SiC Lightweight Optics with Hybrid Skins for Large Cryo Telescopes SBIR

Cryogenic Testing of a 12” Hybrid Skin Silicon Carbide Mirror

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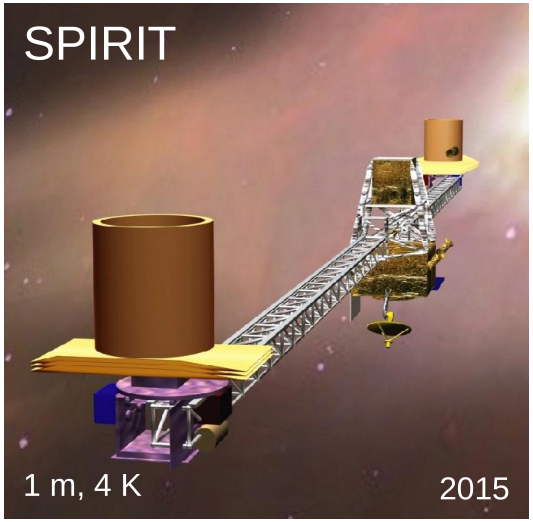
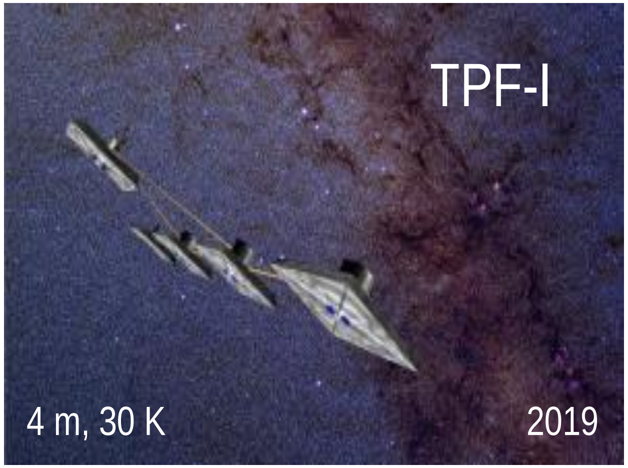
- NASA Cryogenic Missions
- Hybrid Skins for SiC FOCAL Mirrors
- 12” Prototype Mirror Polishing and Pressure Testing
- NASA/XRCF Cryogenic/Optical Testing Chamber
- 12” Prototype Mirror Cryogenic/Optical Testing and Results
- Summary

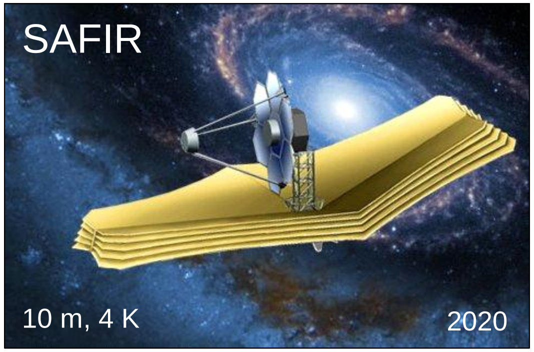
Phase II SBIR Purpose

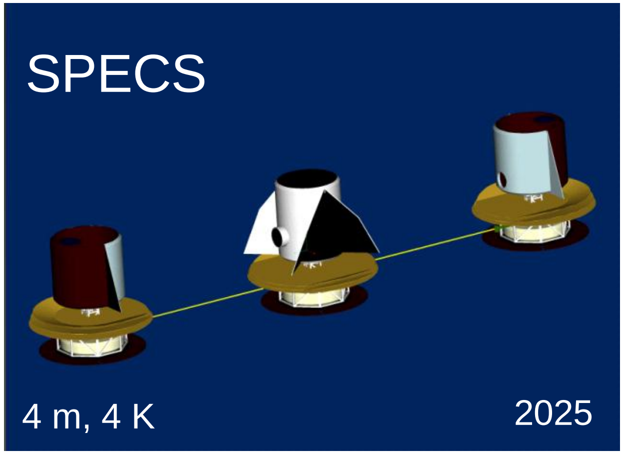
- Future NASA space missions will require 2 to 3 meter class cryogenic mirrors for infrared telescopes
- Silicon carbide (SiC) foam-based optics that are composite, athermal and lightweight (FOCAL) enable internal cooling with cryogenic fluid
- Open-cell foam core mirror technology has evolved over the past ten years and has produced 0.5 m diameter, lightweight, rapidly and uniformly cryo-cooled, and dimensionally stable mirrors configured with .040”-.050” thick monolithic chemical vapor deposited skins.
- Significant problems have arisen as the size has increased that prevent their use on large aperture telescopes which include :
  – Inherent stress in the monolithic skins results in cracking during manufacturing and finishing
  – Non-uniformity of monolithic skins require significant material removal to provide an optical surface
  – Long manufacturing schedule caused by “thick” monolithic skins
  – Large $2M/m2 cost to produce large cryogenic SiC FOCAL mirrors
- SBIR innovation is that the monolithic SiC skins are replaced with hybrid SiC fiber reinforced/SiC CVD skins which consist of a .020”-.030” thick SiC fiber reinforced layer ground to a smooth finish and near net shape and a .005”-.010” thick, 100% dense CVD SiC polishing layer
- Optical finishing cost and schedule is reduced since the hybrid mirror substrates are provided near net shape

Future NASA Missions Requiring Actively Cooled Cryogenic Optic

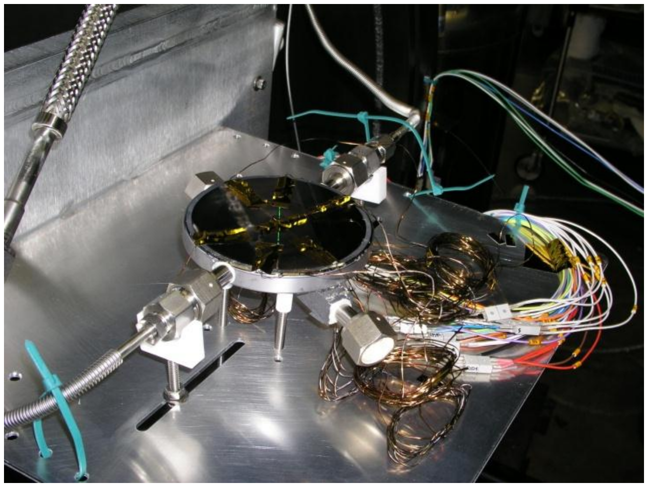


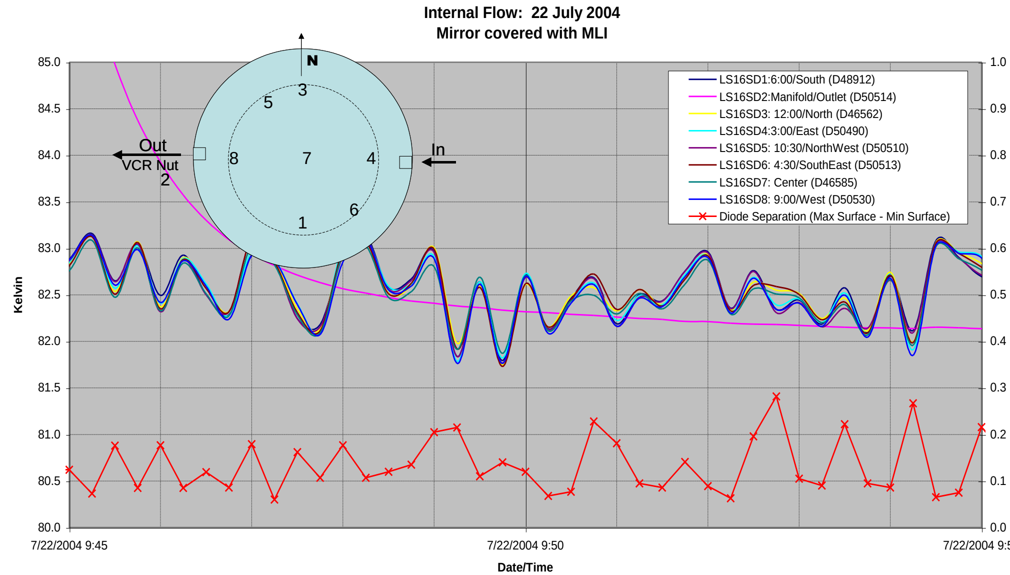






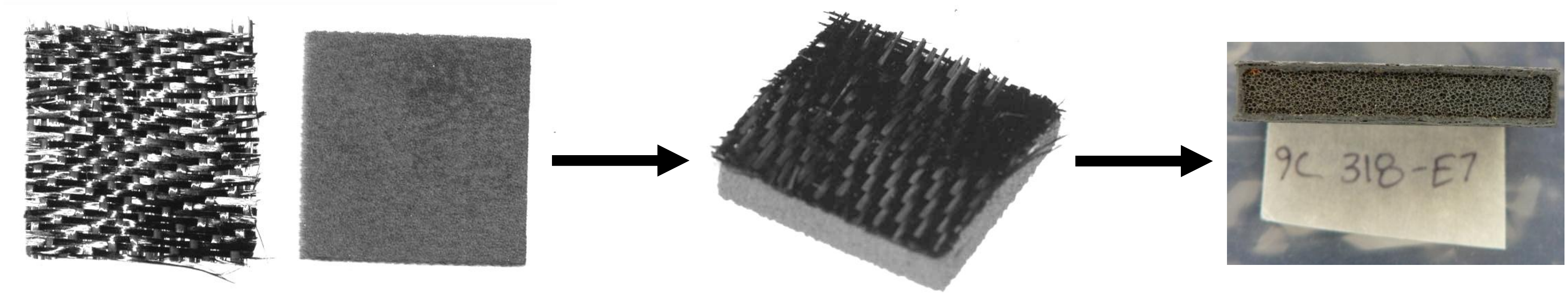
Internally Cryogenic Cooled Foam Optic





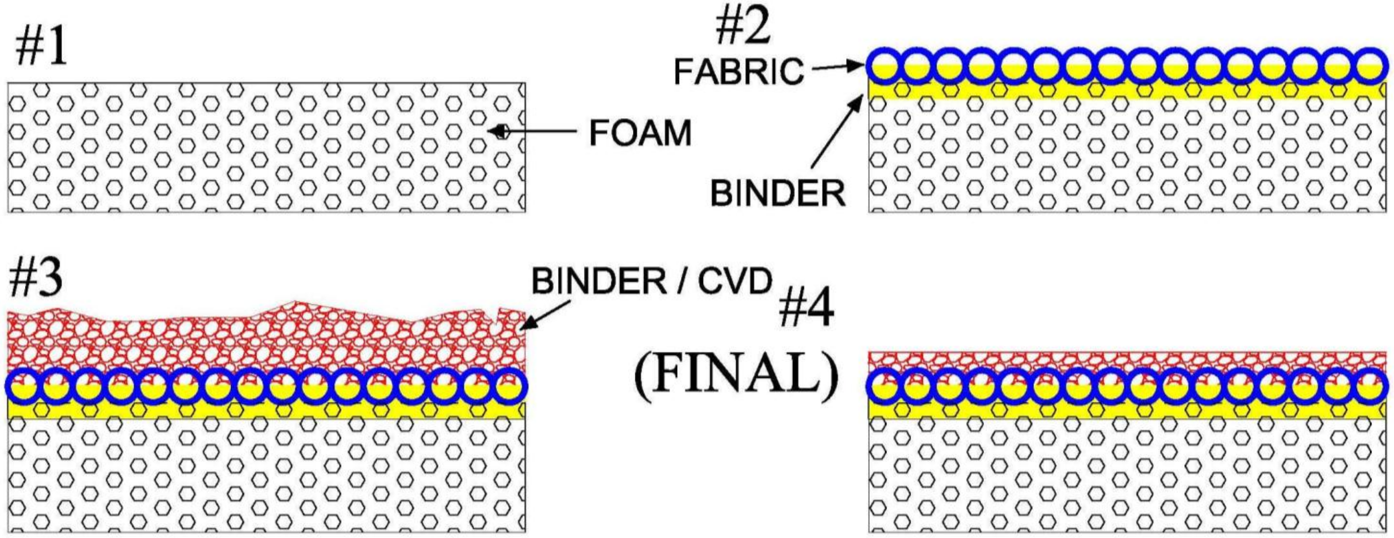
- Experiment done at NASA/MSFC in July 2004 with LN_2
- The test mirror quickly and uniformly reached steady state @ 82.75 ± 0.075 ^{o}K

1.5” x 1.5” x ¼” thk Coupons Hybrid Skin



- Mirror cores of 100 pore per inch, 8-10% density SiC open celled foam
- ~10 different blends / viscosities of SiC particulate and binder tested to optimize attachment of SiC cloth to foam core
- Optimum binder combination selected and used on following 4” dia. x 1” thk Pathfinder

4" dia x 1" thk Flat Pathfinder Hybrid Skin



- 2 mirror cores 100 pores per inch, 10-12% density, SiC open celled foam
- Applied SiC woven cloth composite to flat faces and OD using optimum binder media
- Single step finishing process filled cloth voids with binder media for smooth surface prior to final SiC CVD layer & polishing

4” dia x 1” thk Flat Pathfinder Results

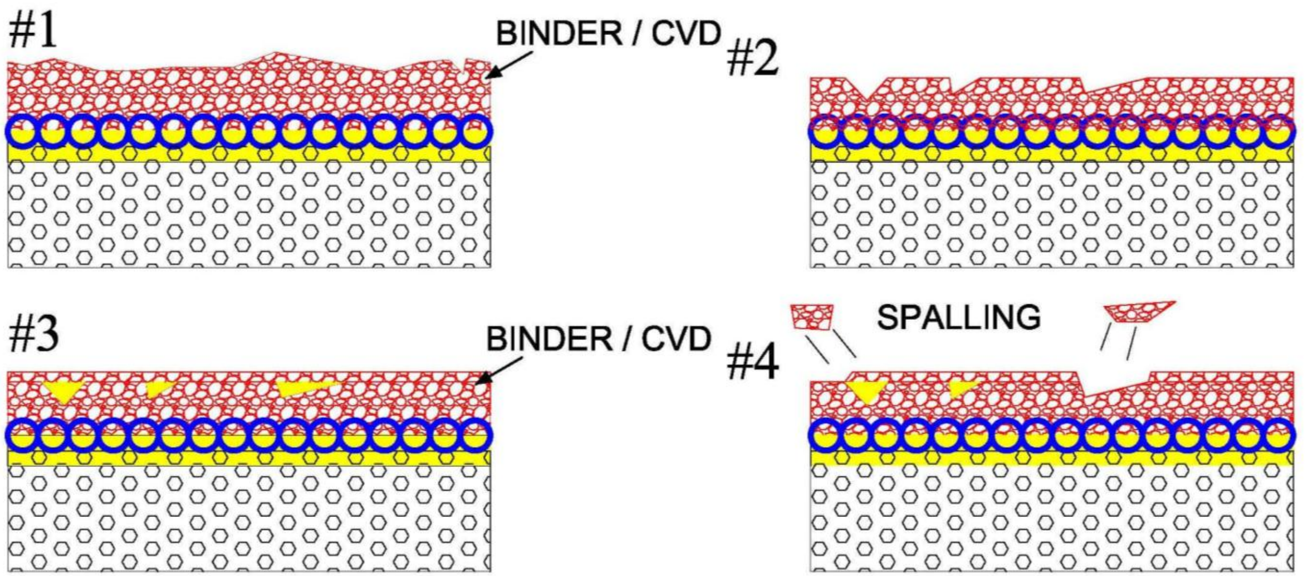
Mirror Shape	Flat
Mirror CA	90%
Mirror thk	1 in
Mirror dia	4 in
Scratch/Dig	60/40
Surface Figure	<0.06 μ rms
Surface Rough	<10 Å rms

- The substrate was polished to 0.04 μ rms by RAD Optical Solutions

12” dia X 2” thk Sphere Prototype Hybrid Skin

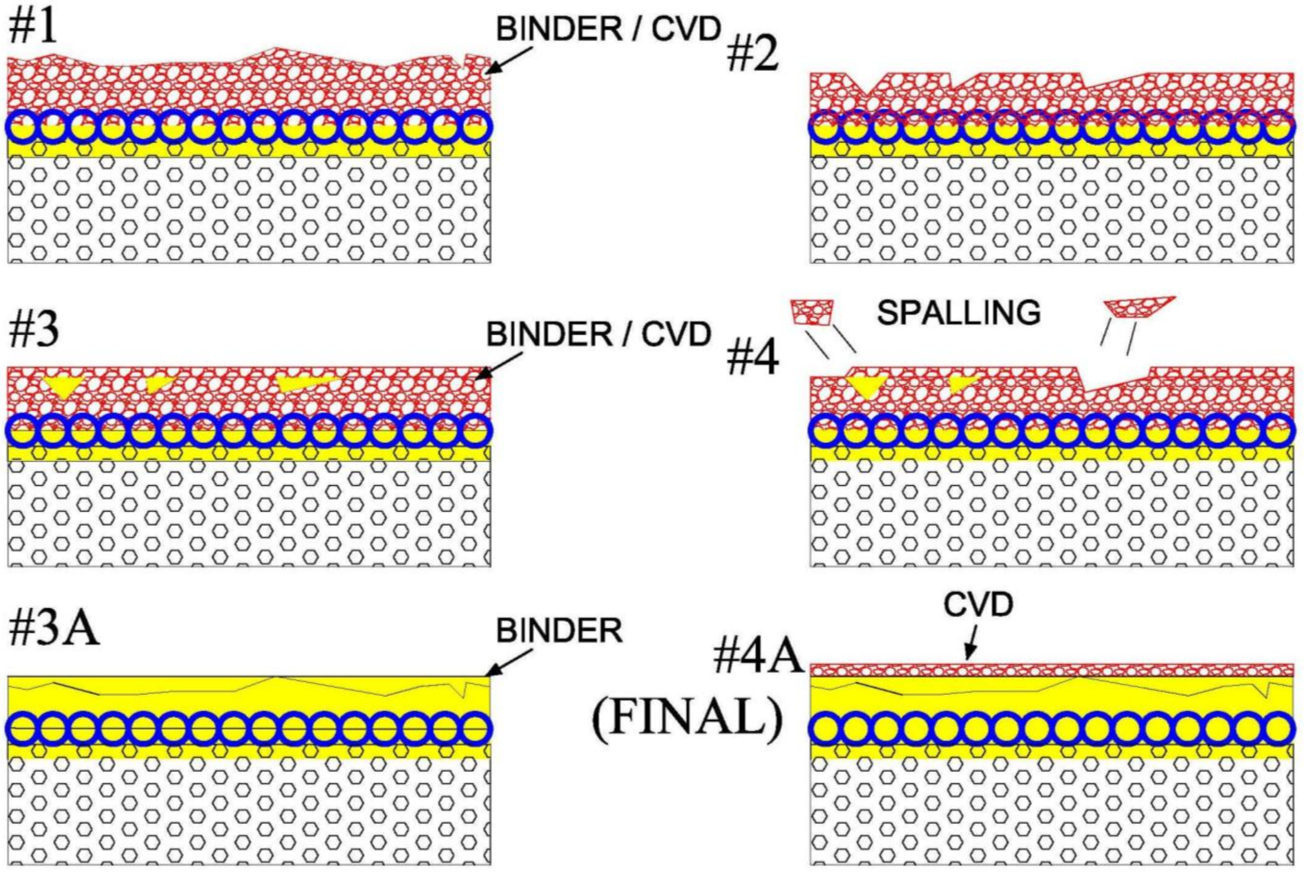
- 80 pore per inch, 11.9% density SiC foam core manufactured and one face machined to F/2 concave spherical optical surface
- Applied SiC woven cloth composite reinforcement to flat back, OD, & concave optical face
- Filled cloth voids with binder / filler media and **provided interim SiC CVD reinforcement layer**
- Re-ground 12” optical surface to re-establish 46” optical radius
- Filled remaining surface voids with binder media and applied final CVD SiC polishing coating

12” dia. Sphere Prototype Hybrid Skin Problem



- Second CVD cycle generated <u>unexpected spalling</u> of optical surface due to combination of compressive stress in initial CVD layer, micro-cracks from interim grind, and initial tensile stress from final SiC CVD layer
- Attempted recovery by filling voids with binder media and final (limited) SiC CVD overcoat
- Repair partially successful, but final grinding of thin final CVD layer exposed some repairs

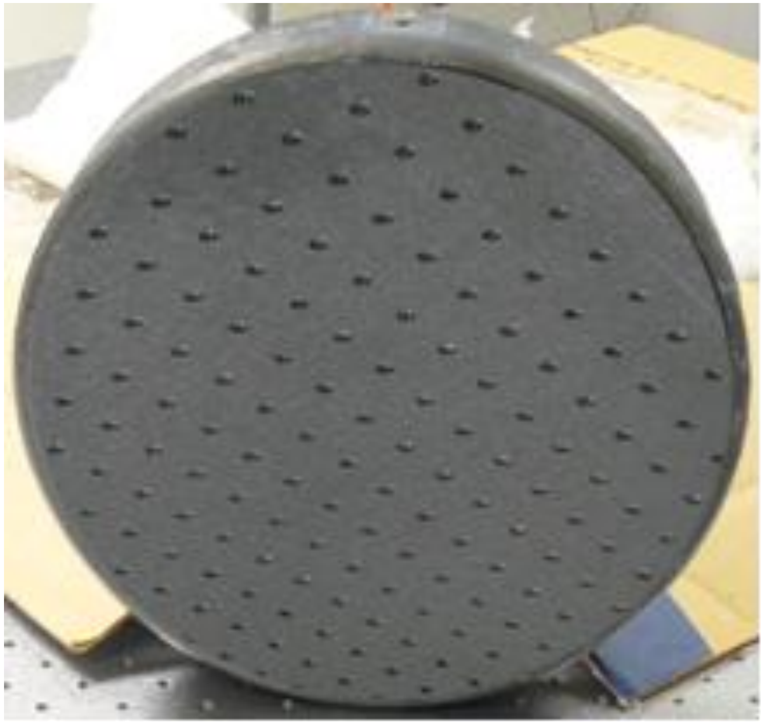
12” dia. Sphere Prototype Hybrid Skin Repair



- CVD/grind/CVD sequence was avoided with alternate manufacturing sequences 3A & 4A

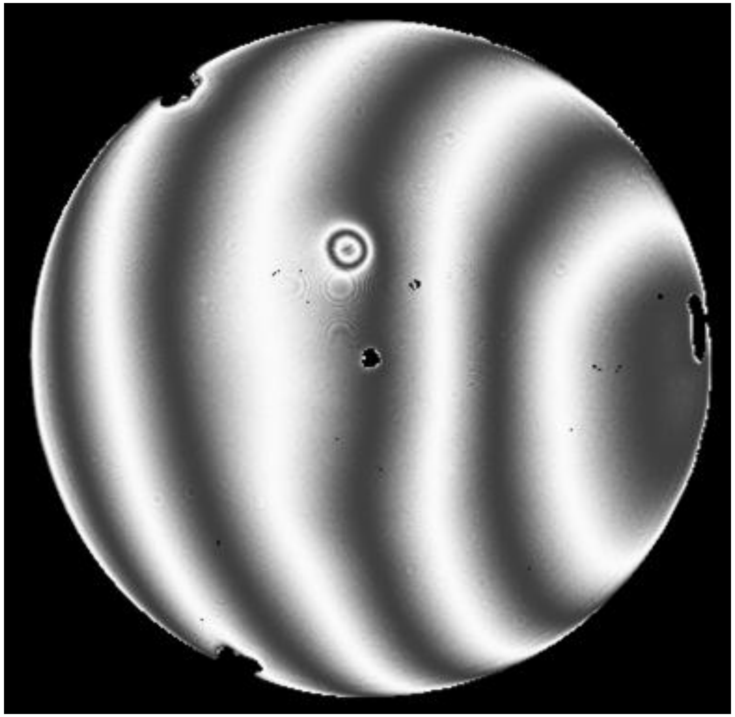
12” dia. Sphere Prototype Polishing Results

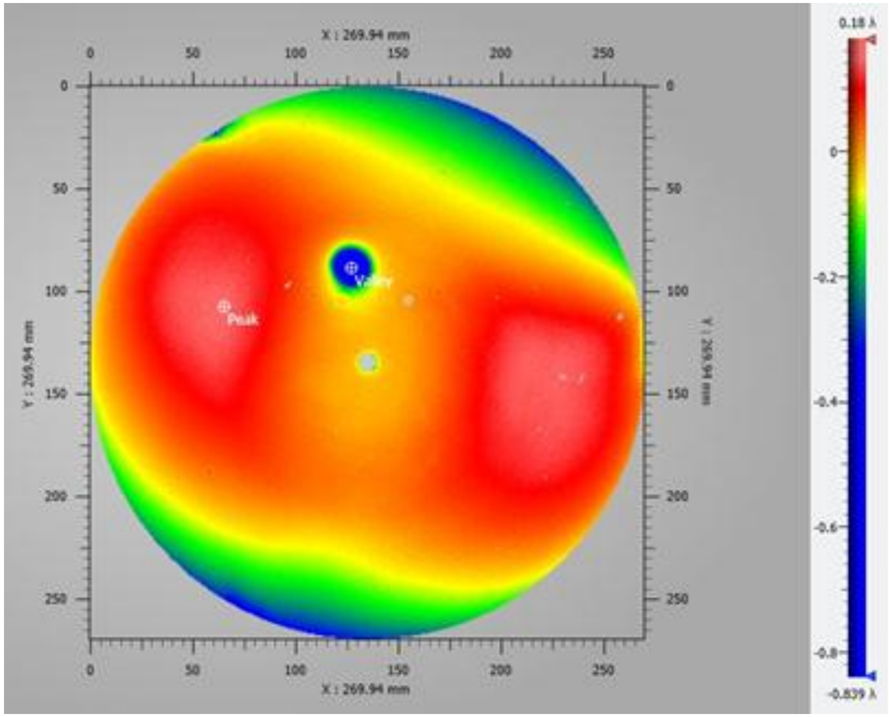
Mirror Shape	F/2 Sphere
Mirror CA	90%
Mirror thk	2 in
Mirror dia	12 in
Scratch/Dig	60/40
Surface Figure	<0.06 µ rms
Surface Rough	<10 Å rms



- The substrate was polished to 0.063 µ rms and 2.7 Å rms by Aperture Optical Sciences

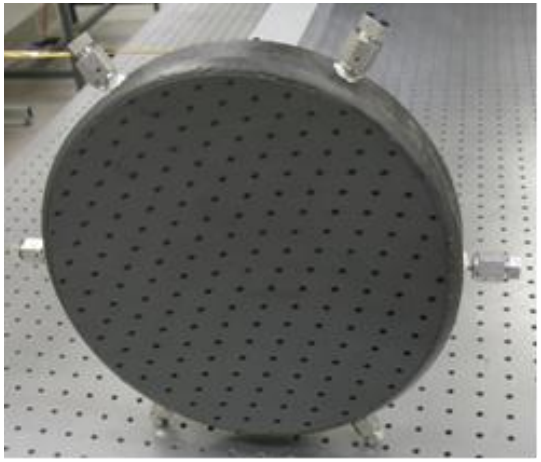
12” Prototype Mirror Imperfections





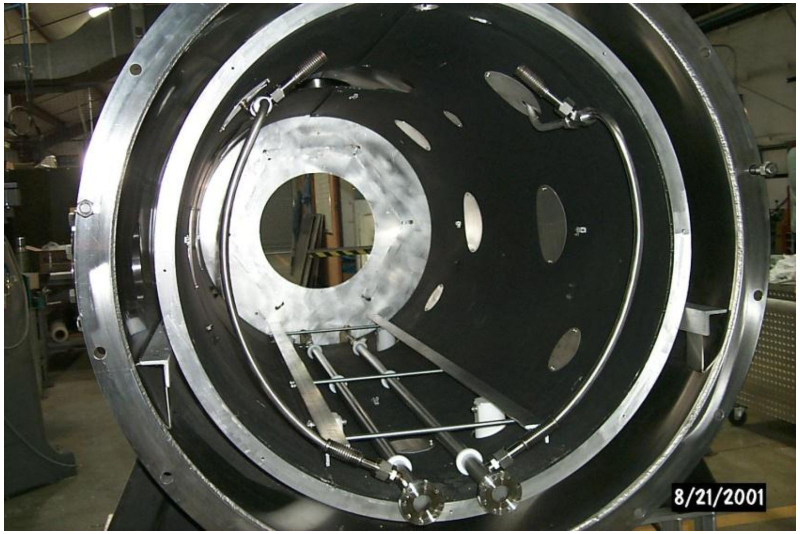
- Stress in the recovered substrate from the initial spalling created imperfections in the optical surface during polishing

12” Prototype Pressure Testing



- VCR fittings were glued to the 12” mirror and it was pressure tested at OPC and NASA/XRCF to 25 psi for use in closed loop cryogenic subsystem

Cryo/Optical Test Chamber



Vacuum Chamber: 1x3 m cylinder with He shroud

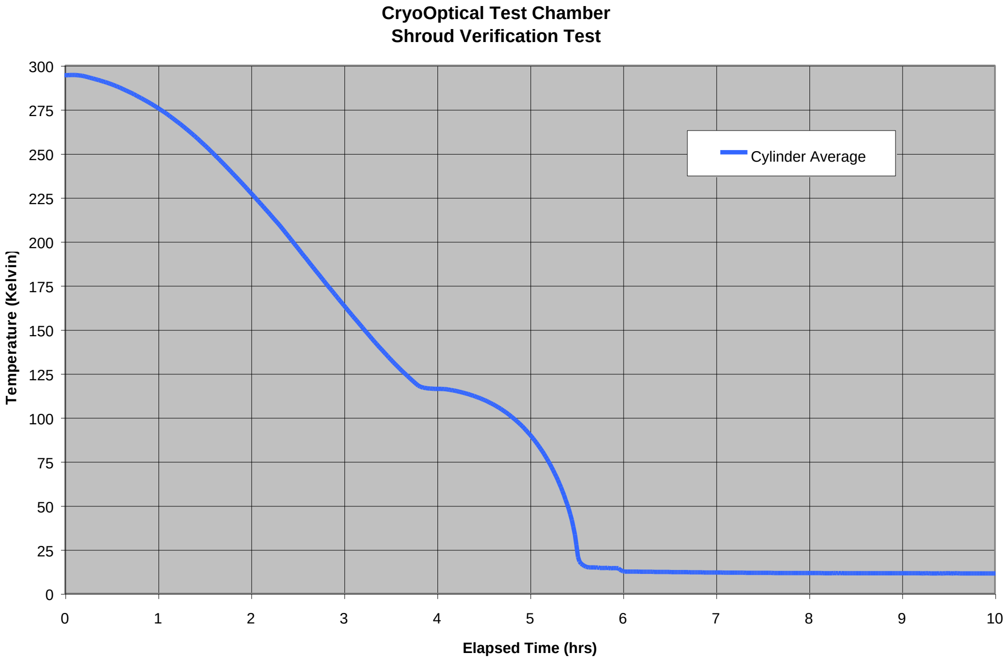
Optical View Ports: BK7 window; 150 mm dia. CA

Precision stage to provide interferometer pointing and alignment

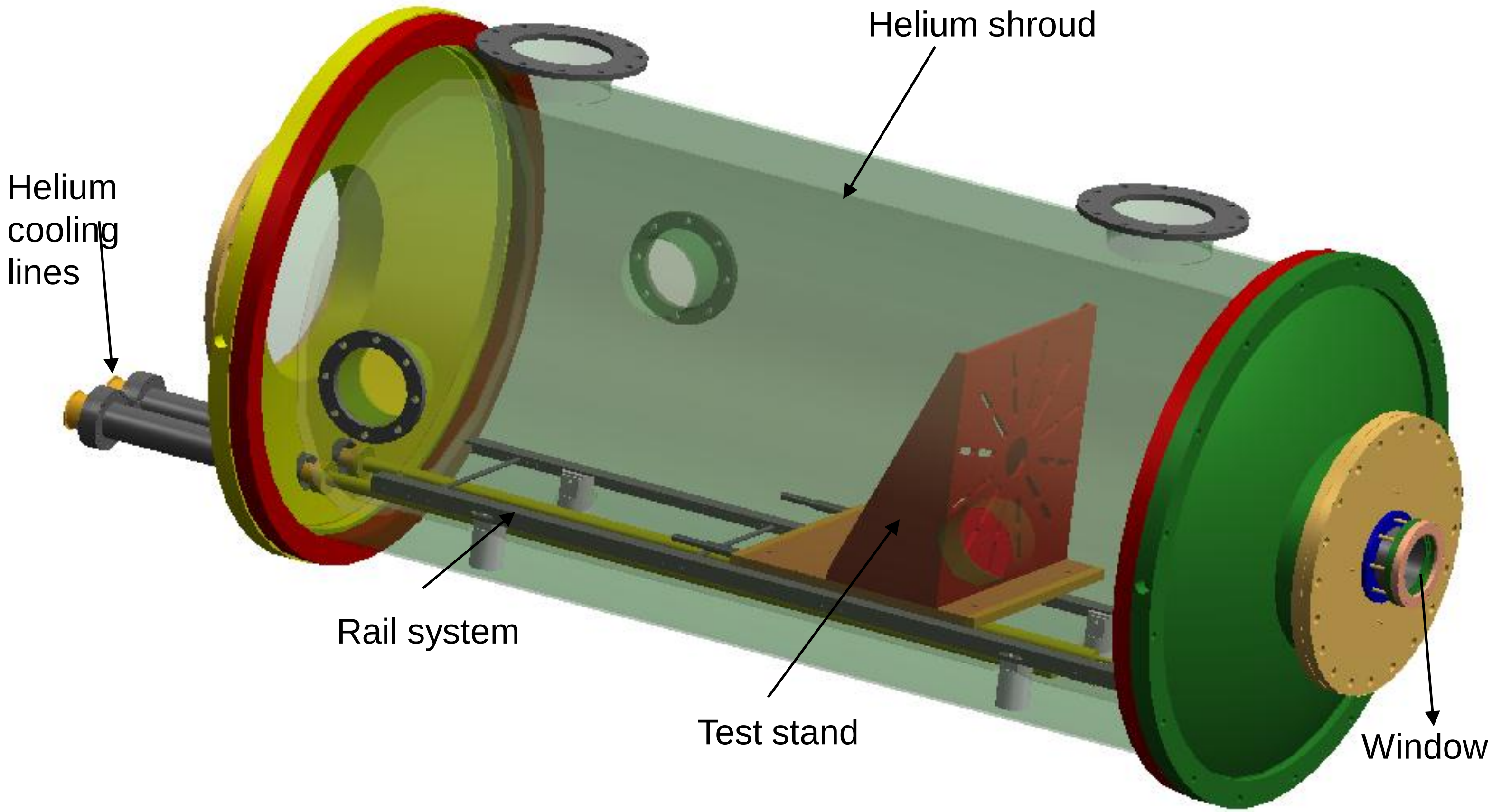
Operational Pressure: < 5 E-6 Torr

Temperature Range: 300 to 12K

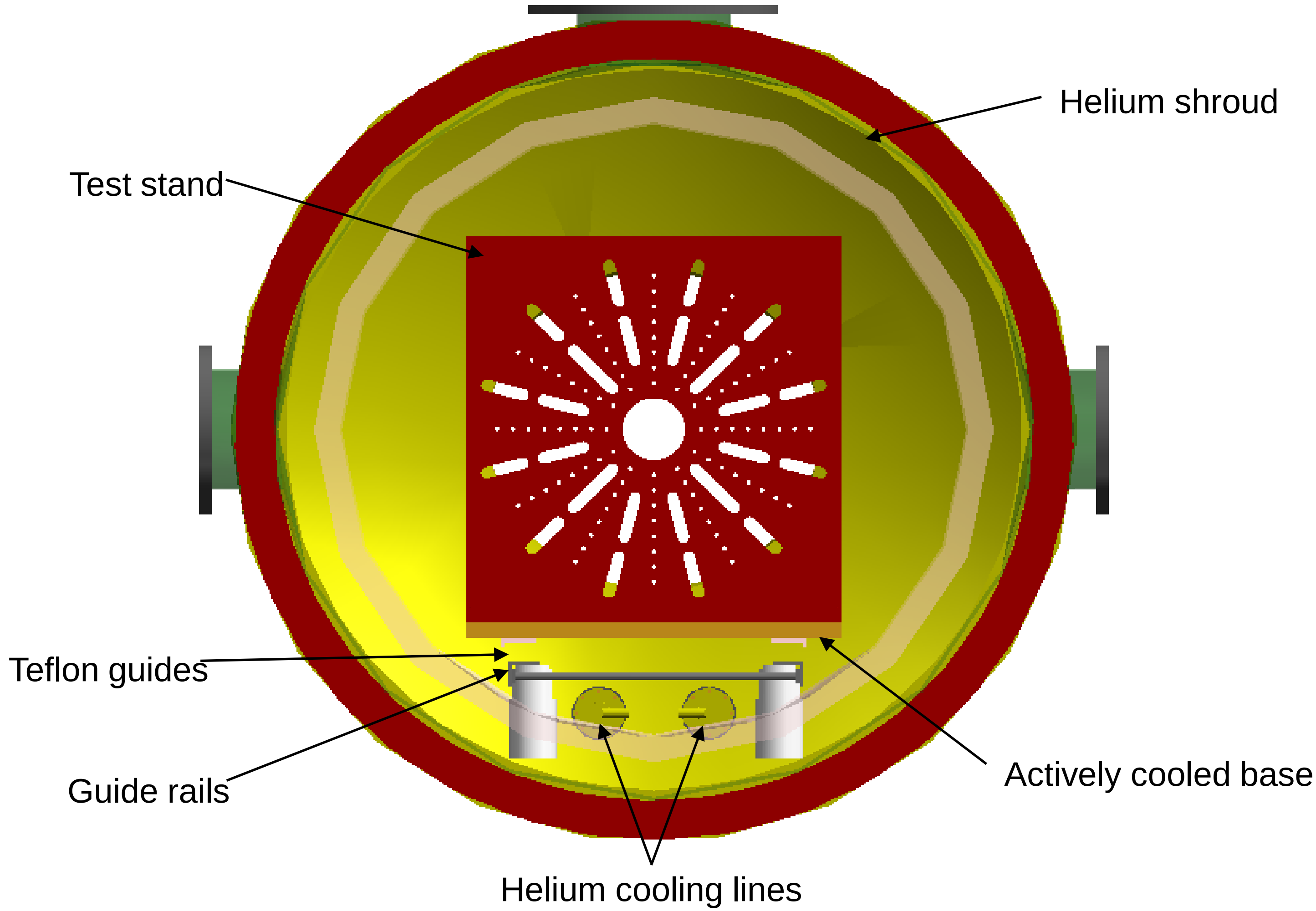
Typical cryo optical test: 290, 200, 100, 70, 50, 30K, 2 cycles; 3 weeks duration



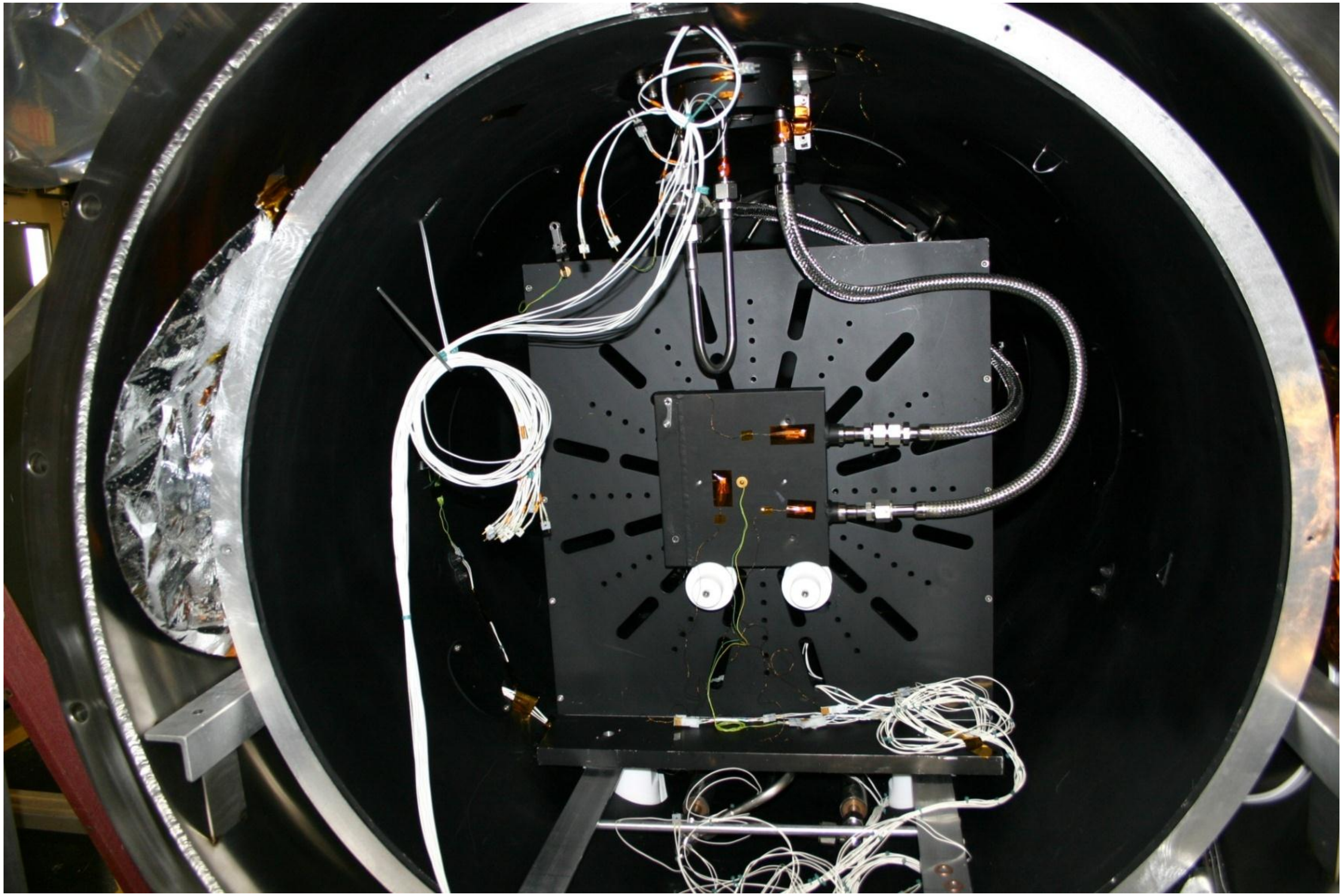
Cryogenic Chamber Side View



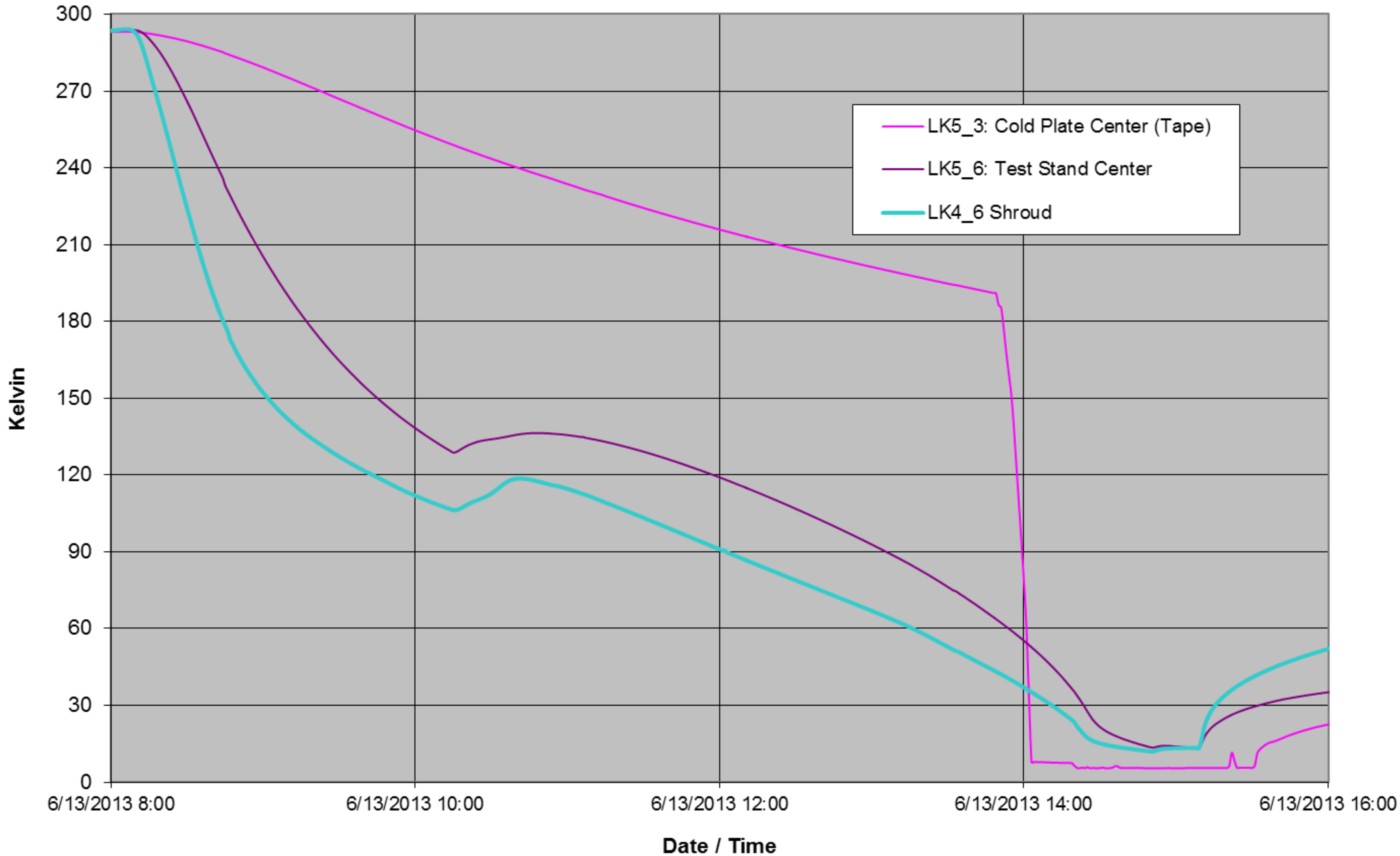
Cryogenic Chamber Front View



Test Chamber Cryogenic Testing

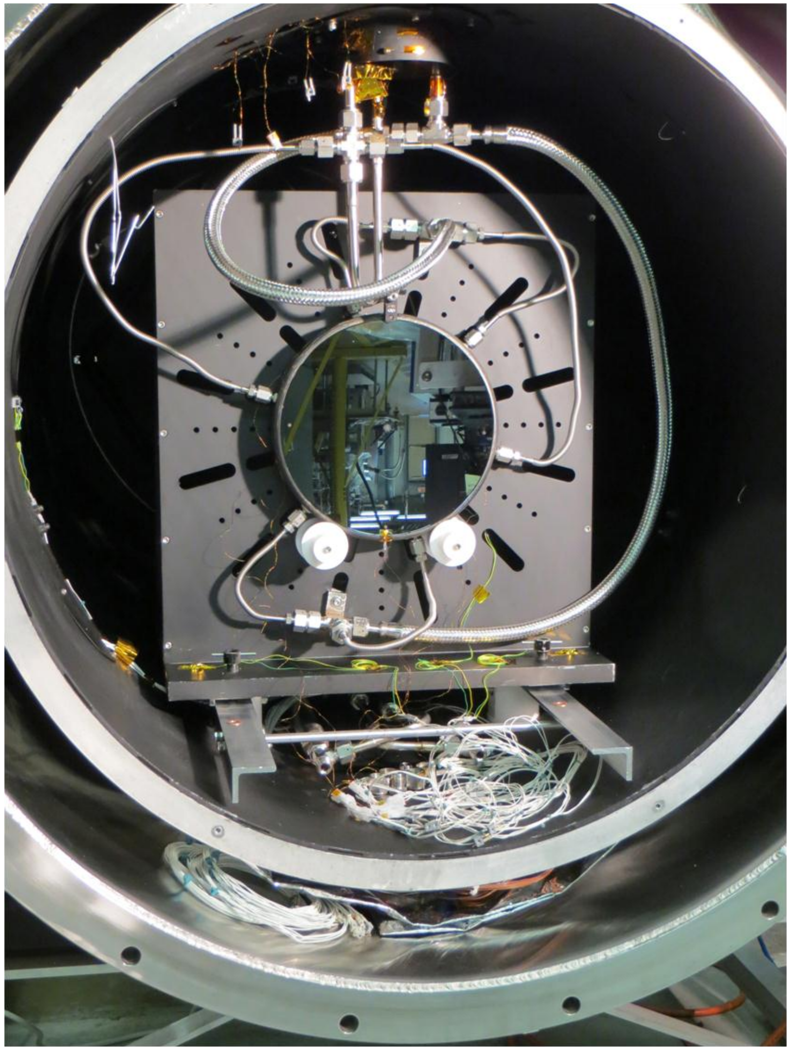


Test Chamber Cryogenic Performance

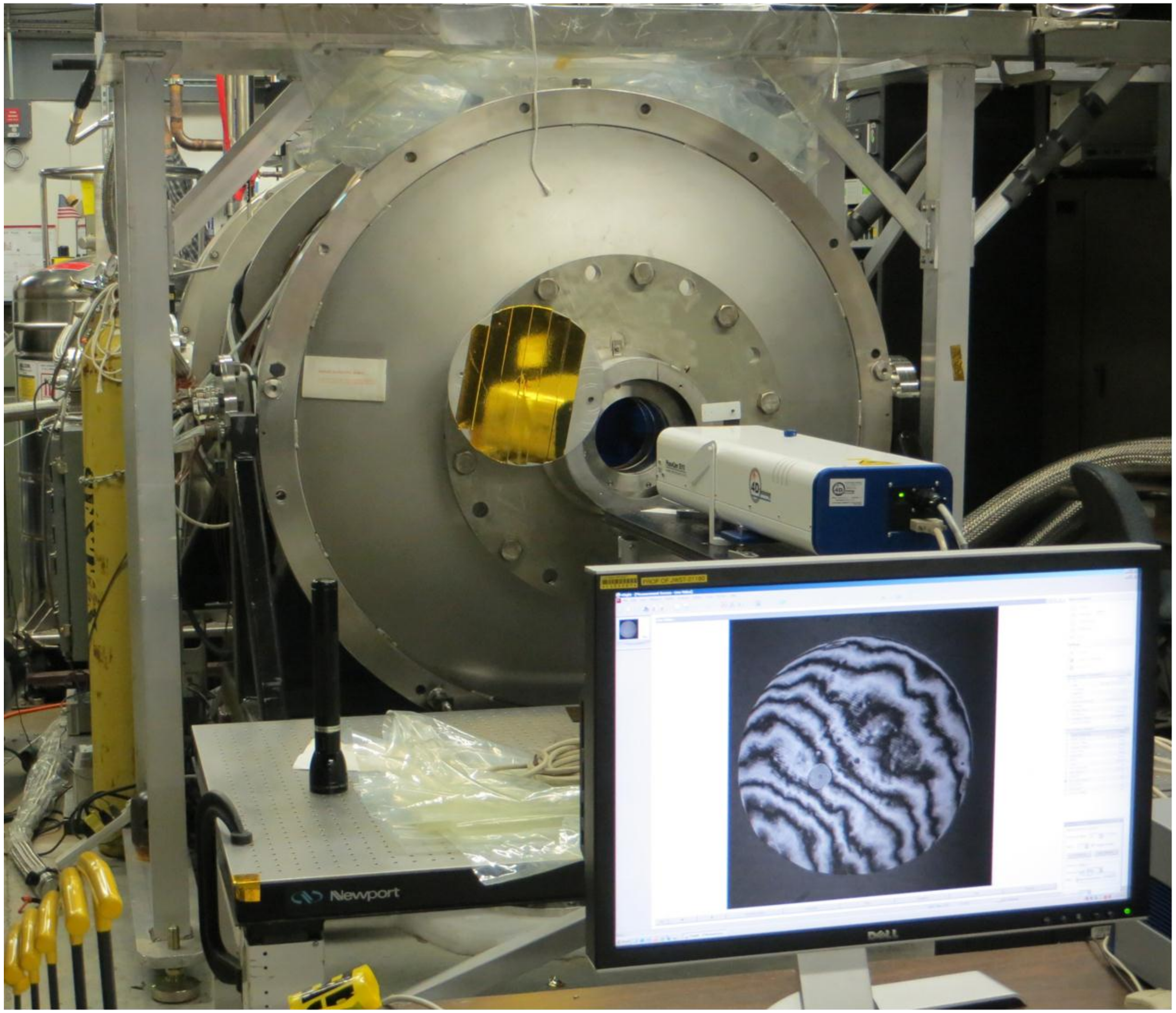


12" Mirror Cryo Test Configuration

- The cryogenic test was configured to simulate the space environment for future NASA missions
- The goal was to cool the mirror with liquid helium to ~5 K in a ~25 K environment (shroud temperature), and then measure the cryogenic figure to compare it with the figure taken in ambient conditions

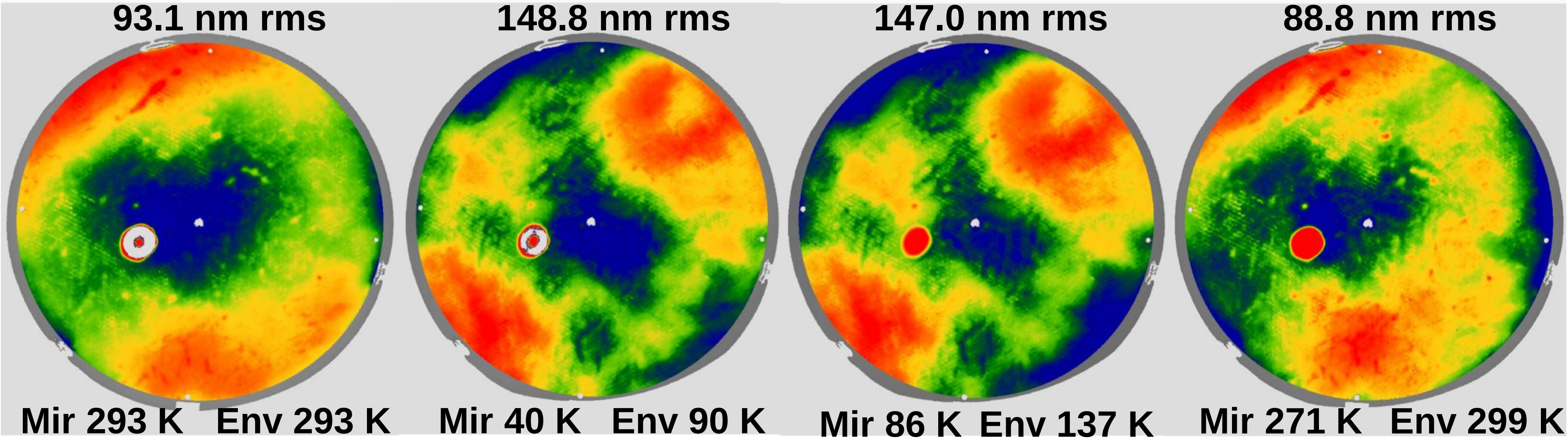


12” Mirror Cryo Testing



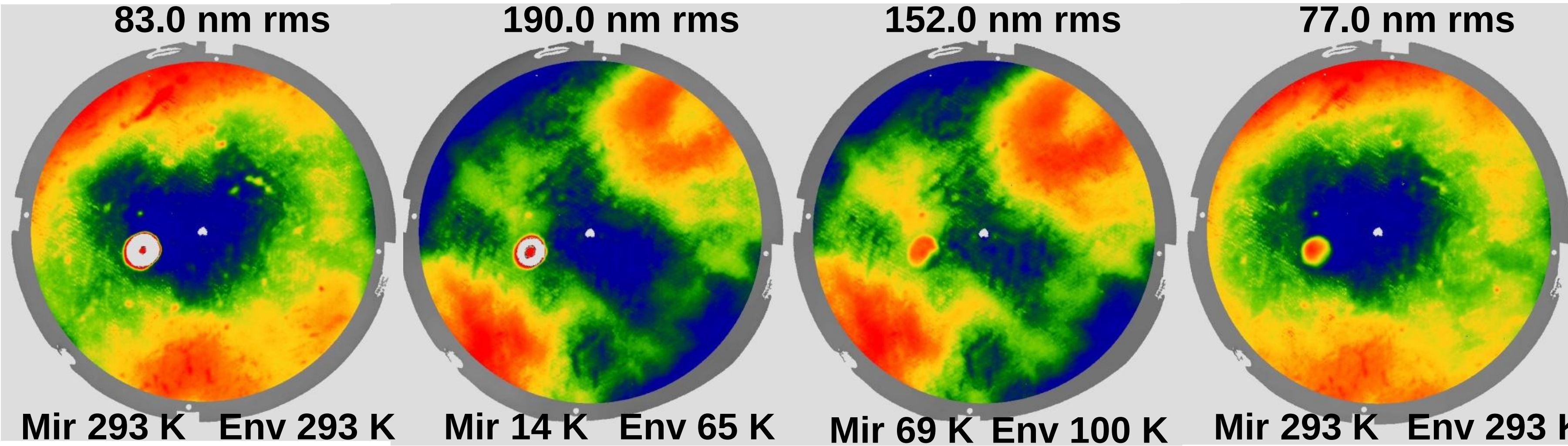
- The mirror figure was measured by a 4D Technology interferometer

12” Mirror Cryo Test Initial Results



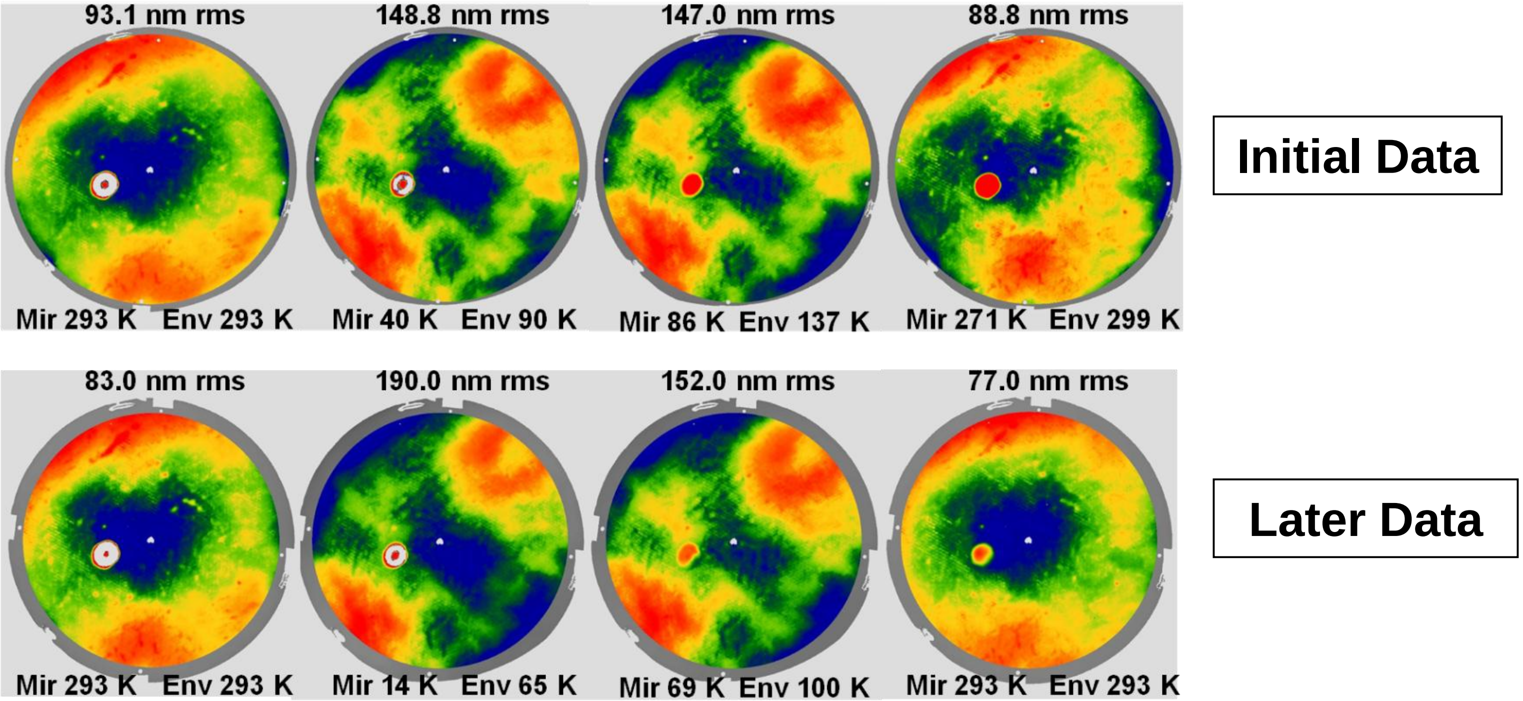
- Optical figure is given over a 95% clear aperture and includes the mirror imperfections - figure is ~2% smaller when they are removed
- The goal of “Mir 5 K / Env 25 K” not reached due to a leaks in a couple of the six glue bonds on the mirror which leaked helium into the chamber
- There is ~0.09 λ rms (λ = 633 nm) change from ambient to cryo
- The mirror figure recovers going from ambient-cryo-ambient

12” Mirror Cryo Test Later Results



- Optical figure is given over a 90% clear aperture and includes the mirror imperfections - figure is ~2% smaller when they are removed
- We repaired a couple of the glue bonds and we did get closer to the goal of “Mir 5 K / Env 25 K” - still some helium leakage into the chamber
- There is ~0.17 λ rms (λ = 633 nm) change from ambient to cryo
- The mirror figure recovers going from ambient-cryo-ambient
- Three cryo cycles were completed and the figure data repeated well

12” Mirror Cryo Test Summary



- The repair of a couple of leaks in the glue bonds got us closer to the goal of “Mir 5 K / Env 25 K”
- There is an additional ~0.08 λ rms error (λ = 633 nm) in going from 40 K in the initial cryo test down to 14 K in the subsequent cryo tests
- The mirror figure recovers going from ambient-cryo-ambient
- Since the figure data repeated very well in multiple cryo cycles, cryo nulling to achieve the best figure at low temperature could be employed

Summary

- Cryogenic testing of a 12” prototype SiC FOCAL mirror was performed at NASA/XRCF
- Multiple cryo cycle results show a repeatable small change in figure from ambient to cryo and figure recovery going from ambient-cryo-ambient which allows for cryo nulling if required to achieve best performance at low temperature
- OPC is now manufacturing another 12” prototype mirror with an improved mandrel process that will produce a “pristine” purpose-built mirror that could reduce the figure change from ambient to cryo and provide a pathway to larger diameter mirrors
- OPC now has a better method to glue the VCR fittings to the 12” mirror so that the simulation of the space environment for future NASA missions of a 5 K mirror in a 25 K environment can be achieved in the NASA/XRCF cryo test chamber